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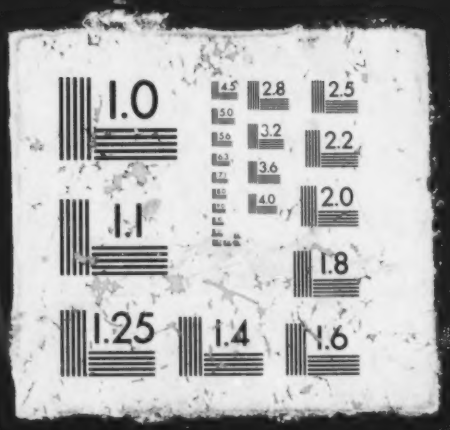

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Toxicity of the Synthetic Pyrethroids Permethrin and AC 222, 705 and Their Accumulation in Early Life Stages of Fathead Minnows and Snails

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16. ABSTRACT

Early life stages of fathead minnows (Pimephales promelas) were exposed to permethrin and AC 222, 705 and snails (Helisoma trivolvis) were exposed to permethrin in continuous flow-through exposures for approximately 30 days. Saturated solutions of each pesticide were used to avoid the use of solvents.

Survival of newly hatched larvae and early juveniles was found to be the most sensitive measure of effect on fathead minnows of both pesticides. AC 222, 705 was approximately 20 times more toxic to fathead minnows than permethrin by the end of the test period. Based on the chronic limits, as defined in these tests, the predicted chronic no-effect concentrations for fathead minnows were between 0.66 and 1.4 µg/l for permethrin and 0.03 and 0.07 µg/l for AC 222, 705. The no-effect concentration for permethrin and snails was $\geq$0.33 µg/l. The chronic values for these compounds were approximately one-sixteenth and one-fourth of the corresponding 96-h LC50 values, respectively, for fathead minnows in Lake Superior water.

The mean bioconcentration factors (BCFs) for permethrin were 2800 for fathead minnows and 800 for snails. The mean BCF for AC 222, 705 and fathead minnows was 4000. Residue concentrations for both pesticides increased with increased water concentrations.

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TOXICITY OF THE SYNTHETIC PYRETHROIDS, PERMETHRIN AND AC 222, 705 AND THEIR ACCUMULATION IN EARLY LIFE STAGES OF FATHEAD MINNOWS AND SNAILS

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Early life stages of fathead minnows (*Pimephales promelas*) were exposed to permethrin and AC 222, 705 and snails (*Helisoma trivolvis*) were exposed to permethrin in continuous flow-through exposures for approximately 30 days. Saturated solutions of each pesticide were used to avoid the use of solvents.

Survival of newly hatched larvae and early juveniles was found to be the most sensitive measure of effect on fathead minnows of both pesticides. AC 222, 705 was approximately 20 times more toxic to fathead minnows than permethrin by the end of the test period. Based on the chronic limits, as defined in these tests, the predicted chronic no-effect concentrations for fathead minnows were between 0.66 and 1.4 μg/l for permethrin and 0.03 and 0.07 μg/l for AC 222, 705. The no-effect concentration for permethrin and snails was ≥0.33 μg/l. The chronic values for these compounds were approximately one-sixteenth and one-fourth of the corresponding 96-h LC_{50} values, respectively, for fathead minnows in Lake Superior water.

The mean bioconcentration factors (BCFs) for permethrin were 2800 for fathead minnows and 800 for snails. The mean BCF for AC 222, 705 and fathead minnows was 4000. Residue concentrations for both pesticides increased with increased water concentrations.

Key words: synthetic pyrethroids; permethrin; AC 222, 705; toxicity; bioaccumulation; early life stages; fathead minnows; freshwater invertebrates

INTRODUCTION

Synthetic pyrethroids are presently manufactured and registered as alternatives to organochlorine, organophosphate, and methylcarbamate insecticides that are considered to have high persistence, adverse environmental impact and/or toxic effects on higher animals including man (Casida, 1980). Pyrethroids developed in the past 7 yr have been found to be more suitable for agricultural use than earlier pyrethrins because of their improved potency and stability as well as low mammalian toxicity. Although the new synthetic pyrethroids have been shown to be highly effective in controlling unwanted animal life such as mosquitos, pestiferous midges, and agricultural pests (Mulla et al., 1978a, b, 1980; Carter and Chadwick, 1978; Hall, 1979; Ali and Mulla, 1980; Rettich, 1980; and American Cyanamid Company, 1981)

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concurrent tests by some of these authors have indicated that they are also toxic to non-target organisms at field application dosages. Studies by Jolly et al. (1978), McLeese et al. (1980), Kumaraguru and Beamish (1981), and Holcombe et al. (1982) demonstrated that some pyrethroids are highly toxic to fish and aquatic organisms and can cause significant mortality in 4 days at concentrations < 10 µg/l. Recent investigations by Anderson (1982) and Spehar et al. (1982) indicated that significant adverse effects on freshwater crustaceans, insects, and early life stages of fish occurred at < 1.0 µg/l in longer-term exposures with the pyrethroids permethrin and fenvalerate. Little or no information is available in the literature on the long-term effects of several pesticides, now being used, on these aquatic organisms.

The principal objective of this study was to predict the chronic no-effect concentration of permethrin, a synthetic pyrethroid used to control cotton insect pests and mosquitos, and AC 222, 705, a newly registered synthetic pyrethroid also used for controlling cotton pests as well as insects on tobacco, fruits, soybeans, corn and vegetables, in tests with early life stages of the fathead minnow (*Pimephales promelas*). The use of early life stage tests for predicting chronic effects of several chemicals has been suggested in a review of the literature by McKim (1977). The unique features of early life stage tests utilizing the fathead minnow were recently described by Benoit et al. (1982). Snails (*Helisoma trivolvis*) were also used for this study because of their availability and were exposed only to permethrin. In addition, the use of snails provided an opportunity to determine the bioaccumulation of this chemical in a lower food chain organism.

MATERIALS AND METHODS

Water characteristics

Lake Superior water was filtered through sand, sterilized with ultraviolet light and heated to 25 ± 2°C for tests with fathead minnows and 15 ± 2°C for tests with snails. Chemical characteristics of the test water were determined weekly (American Public Health Association et al., 1980). Ranges of these measurements (in mg/l as $CaCO_3$) were: hardness, 34–48; alkalinity, 37–46; and acidity, 1.0–4.4. The pH ranged from 7.4–7.9. Dissolved oxygen concentrations ranged from 5.3–7.8 mg/l for fathead minnow tests and 9.2–10 mg/l in tests with snails.

Exposure system

The tests were conducted with a continuous flow mini-diluter exposure system (Benoit et al., 1982) which delivered 5 pesticide concentrations and a control to 4 replicate exposure chambers per concentration. Duplicate exposure chambers per concentration were used with snails due to the small number of animals available. Glass test chambers measured 7 cm wide × 19 cm long × 9 cm high with a water

depth of 4.5 cm. The flow rate to each chamber was 12.5 ± 1 ml/min. Sylvania, Cool White, fluorescent bulbs provided a light intensity of 2 to 6 lux at the water surface during a 16-h photoperiod.

Toxicant solution

Technical grade permethrin, 92% active ingredient [3-(phenoxy-phenyl)methyl (±)-*cis,trans*-3-(2,2-dichloroethenyl)-2,2-dimethyl cyclopropanecarboxylate] and AC 222, 705, 80.6% active ingredient [(±)-cyano(3-phenoxyphenyl)methyl (±)-4-(difluoromethoxy)-α-(1-methylethyl)benzeneacetate] were supplied by ICI Americas, Inc., Goldsboro, NC and the American Cyanamid Company, Princeton, NJ, respectively.

Saturated solutions of permethrin and AC 222, 705 were used as the toxicant source to avoid the use of solvent chemicals. The saturator system for permethrin was the same as that described by Phipps and Holcombe (1982). A concentration of 16 μg/l of permethrin was maintained in the saturator. A saturator system modified from that described by Veith and Comstock (1975) for AC 222, 705 consisted of a 2800 ml glass (Pyrex) flask filled with dilution water and 300 g of sand (containing ~2% AC 222, 705) connected to a reservoir filled with 11 l of water. A concentration of ~5 μg/l of AC 222, 705 was maintained by recirculating the solution through this flask and reservoir. Both pesticides were delivered to the diluter systems via fluid metering pumps to produce the desired concentrations.

Chemical procedures

Water samples for pesticide analyses were collected twice a week and extracted with hexane before analysis by gas chromatography. Permethrin samples were analyzed on a Hewlett–Packard 5713 A gas chromatograph with an auto sampler and a Ni-63 electron capture cell. The column was a 1.0 m × 2 mm (ID) glass coil filled with 3% OV-7 on 80/100 mesh chromosorb W-HP. The carrier gas was argon containing 5% methane. Analyses were run at a column temperature of 220°C. The limit of detection for this procedure was ~0.01 μg/l and the mean percentage recovery and SD for 13 spiked samples were 91 ± 8. The column used for AC 222, 705 water analysis was a 1 m × 2 mm (ID) glass coil filled with 3% OV-7 on 100/120 mesh Gas Chrom Q. The carrier gas was 5% methane utilizing a column temperature of ~300°C. The limit of detection for this method was ~0.01 μg/l and the percentage recovery and SD for 8 spiked samples were 108 ± 6. Measured water concentrations (mean ± SD) for permethrin and AC 222, 705, are shown in Table I.

Biological procedures

Procedures for conducting acute tests with AC 222, 705, generally followed those

TABLE I

Survival and growth of fathead minnows exposed to various concentrations of permethrin and AC 222, 705 for 32 days.

Measured concentration (μg/l)	Embryo hatchability[a] (%)	Normal larvae at hatch (%)	Survival[b] (%)	Mean weight (mg)
		Permethrin		
<0.01[c] (control)	95 ± 3.8	94 ± 2.3	92 ± 13.0	96 ± 25 (55)[e]
0.11 ± 0.04[d]	99 ± 2.0	98 ± 2.3	97 ± 6.0	89 ± 24 (59)
0.18 ± 0.03	96 ± 3.3	96 ± 3.3	97 ± 6.5	96 ± 27 (57)
0.33 ± 0.08	95 ± 3.8	95 ± 3.8	97 ± 4.0	91 ± 26 (58)
0.66 ± 0.16	94 ± 2.3	92 ± 5.7	93 ± 9.4	93 ± 26 (56)
1.40 ± 0.12	95 ± 5.0	95 ± 5.0	2 ± 3.5[f]	110 (1)
		AC 222, 705		
<0.01[c] (control)	96 ± 0.0	95 ± 2.0	92 ± 3.0	126 ± 35 (55)
0.02 ± 0.02[d]	98 ± 2.3	98 ± 2.3	87 ± 6.0	128 ± 34 (51)
0.03 ± 0.01	98 ± 2.3	98 ± 2.3	85 ± 8.4	128 ± 30 (51)
0.07 ± 0.04	97 ± 3.8	96 ± 4.6	75 ± 14.0[f]	129 ± 38 (45)
0.13 ± 0.02	94 ± 6.4	0[f]	2 ± 4.0[f]	110 (1)
0.29 ± 0.09	97 ± 3.8	0[f]	0[f]	–

[a]Hatchability based on 100 embryos per concentration.
[b]Survival based on 60 fish per concentration starting at hatch.
[c]Detection limit of analyses.
[d]Mean ± SD of 10 samples.
[e]Number of fish weighed in parentheses.
[f]Values significantly less ($P = 0.05$) than the controls.

described by the American Society for Testing and Materials (1980). Flow-through acute tests were begun by distributing 5 (~50-day-old) juvenile fish to each replicate chamber. Acute tests with permethrin were not conducted as part of this study since a value was previously obtained for fathead minnows in Lake Superior water (Holcombe et al., 1982).

Early life stage tests with fathead minnows were begun by transferring 25 (<1-day-old) embryos from the Environmental Research Laboratory-Duluth culture unit into 120-ml glass jars with 40 mesh Nytex screen bottoms that were oscillated in the exposure chambers for hatchability studies. After all embryos hatched (~4 to 5 days), 15 larvae were distributed to randomized, replicate chambers to determine the adverse effects on larval and early juvenile survival for a period of 28 days. All animals were fed 3 to 5 ml of brine shrimp nauplii 3 times/day except on weekends when they were fed once daily. After a total of 32 days of exposure, the juvenile fish were killed in ice water, blotted dry, and each fish was weighed to the nearest mg.

A 28-day test with snails was begun by distributing 10 (0.09 to 0.3 g) animals to each duplicate chamber. Snails were obtained from a culture at this laboratory and

were fed aspen and birch leaves previously soaked for 1 mth in Lake Superior water. Soaked leaves were fed ad libitum.

Residue analysis

Fathead minnows and snails that survived the tests were analyzed on a whole body basis (wet weight) for permethrin and AC 222, 705. Methods for preparing tissue for analysis were similar to those described by the U.S. Food and Drug Administration (1980). Gas chromatograph conditions for analysis of both pesticides were similar to those used for water samples. The mean percentage recovery and SD for permethrin and AC 222, 705 were 89 ± 12 (5 spiked samples) and 109 (1 spiked sample), respectively. The limit of detection for both pesticides was approximately 0.01 μg/g. Bioconcentration factors (BCFs) were calculated by dividing the pesticide concentration in whole body tissue by the average measured pesticide concentration in the exposure water.

Statistical analysis

Ninety six hour LC_{50} values were determined with the trimmed Spearman–Karber method described by Hamilton et al. (1977). Daily mortality data of replicate exposure tanks were combined before LC_{50} values were calculated.

In the early life stage tests, survival and embryo hatchability data were transformed to arcsin % (Dixon and Massey, 1957) and individual weights from fish in replicate chambers were pooled before the data were subjected to a one-way analysis of variance ($P=0.05$) and to Dunnett's one-sided comparison of treatment means to controls means ($P=0.05$) (Steel and Torrie, 1960).

RESULTS

Permethrin

Permethrin significantly reduced survival and impaired the swimming ability of 1-day-old larvae at a concentration of 1.4 μg/l (Table I). Survival of larvae exposed to this concentration was reduced to 37% 1 day after hatch. Most of the larvae that survived were convulsive (shuddering and spiraling uncontrollably) for short periods of time. Four days after hatch, only 1 larva remained alive at 1.4 μg/l. Significant reductions in survival were not observed in fish exposed to permethrin concentrations averaging 0.66 μg/l or less. Embryo hatchability, the percentage of normal larvae at hatch and the growth (weight) of fathead minnows were not decreased at any of the permethrin concentrations tested after the 32-day test.

Snail survival was not significantly decreased at any of the concentrations tested (0.03 to 0.33 μg/l) after 28 days. Snails exposed to the highest concentration (0.33

μg/l) responded more slowly when probed than snails exposed to lower concentrations and the control, however, this condition disappeared after the first week and all snails appeared normal by the end of the test.

Mean residue concentrations of permethrin ranged from 0.19 to 4.51 μg/g for whole fathead minnows and 0.02 to 0.34 μg/g for snails (Table II). Residue concentrations in both organisms increased with increased exposure concentrations. The mean BCF and SD based on residue accumulations at water concentrations causing no adverse effects to fathead minnows were 2800 ± 700 after 32 days of exposure. The 28-day BCF and SD of permethrin and snails were 800 ± 150.

AC 222, 705

The median lethal concentrations (LC_{50} values) for juvenile fathead minnows exposed to AC 222, 705 decreased with time and ranged from 0.37 μg/l after 24 h to 0.22 μg/l after 96 h (Fig. 1).

AC 222, 705 significantly reduced survival, impaired swimming ability and caused deformity of newly hatched larvae at the highest concentrations of 0.13 and 0.29 μg/l (Table I). Survival of larvae 1 day after hatch was 32 and 3%, at these concentrations, respectively. Larvae that survived had curved spines and showed behavioral abnormalities similar to those exposed to permethrin. Larvae exposed to 0.07 μg/l were not deformed but the swimming ability of some was impaired. Death of larvae at this concentration occurred periodically and resulted in a significant

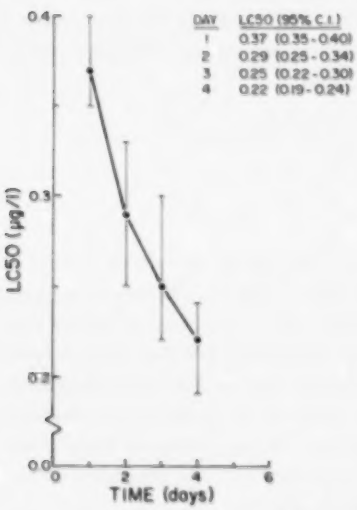

Fig. 1. Relationship between median lethal concentration (LC_{50}) of AC 222, 705 and exposure time for juvenile (~50-day-old) fathead minnows (*P. promelas*).

decrease in survival after 14 days. Significant decreases in survival were not observed in fish exposed to AC 222, 705 concentrations averaging 0.03 μg/l or less. Embryo hatchability and growth of fathead minnows were not decreased at any of the concentrations tested after 32 days of exposure.

Mean residue concentrations of AC 222, 705 in fathead minnows ranged from 0.06 to 0.17 μg/g (Table II). The mean BCF and SD for fathead minnows were 4000 ± 1400.

DISCUSSION

The acute toxicity of AC 222, 705 to juvenile fathead minnows was approximately one-sixth of that reported for this species previously (American Cyanamid Com-

TABLE II

Accumulation of permethrin and AC 222, 705 in fathead minnows (*P. promelas*) and snails (*H. trivolvis*) after ~30 days of exposure.

Species	Measured water concentration (μg/l)	Measured tissue concentration (μg/g, wet weight)	BCF[a]
		Permethrin	
Fathead minnow	<0.01[b] (control)	<0.01[b]	–
	0.11 ± 0.04[c]	0.19 ± 0.02	1700
	0.18 ± 0.03	0.55 ± 0.17	3100
	0.33 ± 0.08	1.01 ± 0.40	3100
	0.66 ± 0.16	2.16 ± 0.36	3300
	1.40 ± 0.12	4.51[d]	–
Snail	<0.01[b] (control)	<0.01[b]	–
	0.03 ± 0.01[c]	0.02 ± 0.01	700
	0.04 ± 0.03	0.03 ± 0.03	800
	0.12 ± 0.05	0.07 ± 0.03	600
	0.22 ± 0.12	0.17 ± 0.04	800
	0.33 ± 0.11	0.34 ± 0.002	1000
		AC 222, 705	
Fathead minnow	<0.01[b] (control)	<0.01[b]	–
	0.02 ± 0.02[c]	0.06 ± 0.04	3000
	0.03 ± 0.01	0.16 ± 0.07	5000
	0.07 ± 0.04	0.17 ± 0.05	–
	0.13 ± 0.02	–[e]	–
	0.29 ± 0.09	–[e]	–

[a]BCFs were calculated from no effect concentrations only.
[b]Detection limit of analyses.
[c]Mean ± SD of 10 samples.
[d]Residue in 1 surviving fish.
[e]Residues were not obtained due to high mortality.

pany, 1981). No other toxicity data for fathead minnows and this chemical were found in the literature for comparison, however, susceptibility differences of aquatic invertebrates and fish exposed to permethrin have been shown to be related to body weight and water temperature (Jolly et al., 1978; Kumaraguru and Beamish, 1981). In these studies, smaller organisms were more susceptible to permethrin than larger ones and toxicity decreased with increased water temperature. The weight of fathead minnows in the present study was approximately one-third of that reported earlier for this species which could have accounted for their greater susceptibility. Water temperature in these studies was approximately the same and probably did not contribute to the toxicity difference observed.

Acute toxicity tests with fathead minnows in Lake Superior water indicated that AC 222, 705 was more toxic than fenvalerate, and permethrin (Holcombe et al., 1982). Recent results reported for rainbow trout (American Cyanamid Company, 1981; Holcombe et al., 1982) and several saltwater species (Schimmel et al., 1982) indicate the same order of toxicity for these chemicals. Rainbow trout were found to be more sensitive to all 3 chemicals than fathead minnows. The 96-h LC_{50} value of 0.09 μg/l obtained for rainbow trout (American Cyanamid Company, 1981) and AC 222, 705 in flow-through exposures was the lowest value obtained for several freshwater species of fish and compares to the chronic effect concentration for fathead minnows in our study. The acute value for AC 222, 705 and fathead minnows was the same as that observed for the pink shrimp (*Penaeus duoram*) (Schimmel et al., 1982); however, the 96-h LC_{50} values for rainbow trout and fathead minnows were nearly 11 and 30 times greater than the value of 0.008 μg/l, respectively, for the estuarine mysid (*Mysidopsis bahia*). Comparison of acute values for permethrin indicated that rainbow trout were twice as sensitive as fathead minnows (Holcombe et al., 1982) but their sensitivity was similar to that of the saltwater sheepshead minnow (Schimmel et al., 1982). Saltwater invertebrates were nearly 800 times more sensitive to permethrin than fathead minnows after 96 h.

In the early life stage tests, survival of larvae and early juveniles of fathead minnows was the most sensitive measure of effect. Both permethrin and AC 222, 705 decreased survival at concentrations which did not decrease the percentage hatchability of embryos or growth of larvae after 32 days of exposure. While no information was found in the literature regarding the chronic effects of these chemicals on freshwater fish, similar results were observed for early life stages of the saltwater sheepshead minnow (*Cyprinodon variegatus*) (Hansen, pers. comm. 1982). Other adverse effects such as larval deformity and convulsive behavior were also noted in exposures with these chemicals in both species of fish. Spehar et al. (1982) observed the same abnormalities in newly hatched fathead minnows exposed to fenvalerate (Pydrin, a synthetic pyrethroid closely related to AC 222, 705). The observed loss of equilibrium and uncontrolled motions of these organisms are characteristic of nervous system disruptions, often seen in exposures with organochlorine pesticides (Spehar et al., 1982). Although little is known about the mode of action of synthetic

pyrethroids in fish, Casida (1981) reported that these insecticides are nerve poisons and act at nerve membranes in invertebrates, principally by altering sodium conductance mechanisms.

After 32 days of exposure, AC 222, 705 was 20 times more toxic to early-life-stages of fathead minnows than permethrin based on a comparison of their chronic values (geometric mean of the chronic limits). The upper chronic limits (the lowest concentrations which caused significant decreases from the control) were 0.07 and 1.4 μg/l for these pesticides, respectively. The lower chronic limits (the highest tested concentrations which did not cause significant decreases from the control) were 0.03 μg/l for AC 222, 705 and 0.66 μg/l for permethrin. The chronic limits for AC 222, 705 and fathead minnows were nearly identical to those found for the sheepshead minnow of 0.03–0.06 μg/l (Hansen, pers. comm., 1982) after the same exposure time. Chronic limits for permethrin and sheepshead minnow, however, were approximately 15 times greater than the values reported for fathead minnows in this study. Reasons for the difference in susceptibility of these species to permethrin are not clearly understood.

Chronic values for fathead minnows exposed to permethrin and AC 222, 705 were approximately one-sixteenth and one-fourth of the corresponding 96-h LC_{50} values, respectively, in Lake Superior water.

The present data indicate that both permethrin and AC 222, 705 are toxic at low concentrations to early-life-stages of the fathead minnow. The chronic value of 0.96 μg/l calculated for permethrin and this species, for example, was lower than the effect levels reported for some target organisms in field studies (Mulla et al., 1980). Investigations by Mulla et al. (1978a, b), Mulla et al. (1980), Rettich (1980), and Friesen (1981) have similarly shown that permethrin and other pyrethroids are toxic to crustaceans, aquatic insects, and fish at field applied dosages. Adverse effects were seen after short-term exposures to these compounds, usually in 1 to 5 days. Muirhead-Thomson (1978) estimated an LC_{90-95} value of 1 μg/l for permethrin based on mortalities 24 h after a 1 h exposure with amphipods, mayflies, and caddisflies. More recent investigations by Anderson (1982) have shown that some aquatic invertebrates are even more sensitive to these compounds when tested in longer-term, flow-through exposures. The LC_{50} values based on tests up to 28 days for stoneflies, caddisflies, mayflies, dipterans, amphipods and snails decreased with increased exposure time. Behavioral changes and/or mortality were observed at a concentration of 0.03 μg/l for permethrin. Fenvalerate was even more toxic than permethrin to these organisms, as was noted earlier for fish, causing adverse effects at 0.022 μg/l within 6 days. Although direct comparisons cannot be made between laboratory results and field applications of AC 222, 705 due to the lack of field experiments with the non-target organisms, the extremely low effect levels obtained in the laboratory suggest that toxicity due to this compound may occur at even lower levels than those caused by permethrin or fenvalerate to more sensitive aquatic invertebrates. Schimmel et al. (1982) have stated that based on unusually high in-

vertebrate sensitivity to AC 222, 705, present detection limit concentrations would likely cause adverse effects to some aquatic biota.

Residue concentrations of permethrin and AC 222, 705 in fathead minnows and snails increased slightly with increased water concentrations after approximately 30 days of exposure. The BCF obtained for fathead minnows and AC 222, 705 was slightly higher than that for permethrin. This result was similar to that found for sheepshead minnows (Hansen, pers. comm., 1982), although BCFs were 2 to 6 times higher for fathead minnows with permethrin and AC 222, 705, respectively. Bioconcentration factors for fathead minnows were about 2 times higher than those observed for the eastern oyster (*Crassostrea virginica*) (Schimmel et al., 1982). Steady-state concentrations in their study were achieved in <2.5 days with permethrin and 7.7 days with AC 222, 705. In these tests each pyrethroid depurated from the tissue to non-detectable concentrations within one week after exposure was terminated.

In the present test, the BCF for permethrin and fathead minnows was approximately 4 times higher than that calculated for snails. Comparison of recent studies by Spehar et al. (1982) and Anderson (1982) similarly showed that fathead minnows had higher BCFs of fenvalerate than snails exposed for the same time in Lake Superior water. The reasons for the lower accumulation of permethrin and fenvalerate in snails compared to fish in these studies are not clearly understood since these findings are contrary to those found for snails and fish exposed to the (S)-acid isomer of fenvalerate in a model ecosystem study (Ohkawa, 1980). Although direct comparisons between the above studies cannot be made due to differences in exposure methodology, BCFs for [^{14}C]fenvalerate in the model ecosystem were found to be lower in fish than in daphnids, snails and algae. This result was attributed by the author to the fish's ability to metabolize [^{14}C]fenvalerate and eliminate metabolites more readily than the lower food chain organisms. However, water concentrations in the model ecosystem decreased with time and high levels remained in the sediment which could have accounted for the low accumulation in fish after 30 days and the higher levels in snails which feed directly in the bottom sediment. In contrast, fathead minnows and snails in the present test were exposed to constant pesticide water concentrations with no sediment present. Bioaccumulation differences in our tests may also have been due to factors such as difference in uptake rates, water temperature and/or differences in the animals' lipid content. Synthetic pyrethroids are known to be highly lipophilic compounds (Casida, 1980).

Synthetic pyrethroid insecticides are not expected to biomagnify through the food chain due to their high sorption to and immobility in soil (Casida, 1980; Rawn, 1981; and American Cyanamid Company, 1981) and because they are rapidly eliminated from tissue after the termination of exposure. However, their persistence in aquatic systems may be sufficient to cause environmental impact from direct field application because of their extremely high toxicity and fast-acting nature.

REFERENCES

Ali, A. and M.S. Mulla, 1980. Activity of organophosphate and synthetic pyrethroid insecticides against pestiferous midges in some southern California flood control channels. Mosq. News 40, 593–597.

American Cyanamid Company, 1981. Cybolt pyrethroid insecticide. Agricultural Research Division, Princeton, NJ.

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1980. Standard methods for the examination of water and waste water. 15th ed., Washington, D.C. 1134 pp.

American Society for Testing and Materials, 1980. Standard practice for conducting acute toxicity tests with fishes, macroinvertebrates, and amphibians. Philadelphia, PA, p. E729–80.

Anderson, R.L., 1982. Toxicity of fenvalerate and permethrin to several nontarget aquatic invertebrates. Environ. Entomol. 11, in press.

Benoit, D.A., F.A. Puglisi and D.L. Olson, 1982. Fathead minnow (*Pimephales promelas*) early life stage toxicity test method evaluation and exposure to four organic chemicals. Environ. Pollut. 28, 189–197.

Carter, S.W. and P.R. Chadwick, 1978. Permethrin as a residual insecticide against cockroaches. Pestic. Sci. 9, 555–565.

Casida, J.E., 1980. Pyrethrum flowers and pyrethroid insecticides. Environ. Health Perspect. 34, 189–202.

Dixon, W.J. and F.J. Massey, Jr. 1957. Introduction to statistical analysis. 2nd ed. McGraw-Hill Book Co., Inc., New York, 488 pp.

Friesen, M.K., 1981. Effects of the insecticide permethrin on the aquatic life stages of the burrowing mayfly, *Hexagenia rijida* (Ephemeroptera: Ephemeridae). Master of Science Thesis, University of Manitoba, Manitoba, Canada, 75 pp.

Hall, F.R., 1979. Effects of synthetic pyrethroids on major insects and mite pests of apple. J. Econ. Entomol. 72, 441–446.

Hamilton, M.A., R.C. Russo and R.V. Thurston, 1977. Trimmed Spearman Karber method for estimated median lethal concentrations in toxicity bioassays. Environ. Sci. Technol. 7, 714–719. Correction 12, 417 (1978).

Hansen, D.J., 1982. Personal communication. U.S. EPA, Environmental Research Laboratory, Gulf Breeze, FL.

Holcombe, G.W., G.L. Phipps and D.K. Tanner, 1982. The acute toxicity of kelthane, dursban, disulfoton, pydrin, and permethrin to fathead minnows (*Pimephales promelas*) and rainbow trout (*Salmo gairdneri*). Environ. Pollut., in press.

Jolly, A.L., Jr., J.W. Avault, Jr., K.L. Koonce and J.B. Graves, 1978. Acute toxicity of permethrin to several aquatic animals. Trans. Am. Fish. Soc. 107, 825–827.

Kumaraguru, A.K. and F.W.H. Beamish, 1981. Lethal toxicity of permethrin (NRDD-143) to rainbow trout, *Salmo gairdneri*, in relation to body weight and temperature. Water Res. 15, 503–505.

McKim, J.M., 1977. Evaluation of tests with early life stages of fish for predicting long-term toxicity. J. Fish. Res. Board Can. 34, 1148–1154.

McLeese, D.W., C.D. Metcalfe and V. Zitko. 1980. Lethality of permethrin, cypermethrin and fenvalerate to salmon, lobster, and shrimp. Bull. Environ. Contam. Toxicol. 25, 950–955.

Muirhead-Thomson, R.C., 1978. Lethal and behavioral impact of permethrin (NRDC-143) on selected stream macroinvertebrates. Mosq. News 38, 185–190.

Mulla, M.S., H.A. Navvab-Gojrati and H.A. Darwazeh, 1978a. Toxicity of mosquito larvicidal pyrethroids to four species of freshwater fishes. Environ. Entomol. 7, 428–430.

Mulla, M.S., H.A. Navvab-Gojrati and H.A. Darwazeh, 1978b. Biological activity and longetivity of new synthetic pyrethroids against mosquito and some nontarget insects. Mosq. News 38, 90–96.

Mulla, M.S., H.A. Darwazeh and M.S. Dhillon, 1980. New pyrethroids as mosquito larvicides and their effects on nontarget organisms. Mosq. News 40, 6–12.

Ohkawa, H., R. Kikuchi and J. Miyamoto, 1980. Bioaccumulation and biodegradation of the (S)-acid isomer of fenvalerate (Sumicidin) in an aquatic model ecosystem. J. Pestic. Sci. 5, 11–22.

Phipps, G.L. and G.W. Holcombe, 1982. Saturator system for generating toxic water solutions for aquatic bioassays. Prog. Fish Cult. 44, 115–116.

Rawn, G.P., 1981. Fate and degradation of permethrin in a model aquatic ecosystem. Ph.D. Thesis, University of Manitoba, Manitoba, Canada, 130 pp.

Rettich, F., 1980. Field evaluation of permethrin and decamethrin against mosquito larvae and pupae (Diptera, Culcidae). Acta Entomol. Bohemoslov. 77, 89–96.

Schimmel, S.C., R.L. Garnas, J.M. Patrick, Jr. and J.C. Moore, 1983. Acute toxicity, bioconcentration, and persistence of AC 222, 705, benthiocarb, chlorpyrifos, fenvalerate, methyl parathion, and permethrin in the estuarine environment. J. Agric. Food Chem., in press.

Spehar, R.L., D.K. Tanner and J.H. Gibson, 1982. Effects of kelthane and pydrin on early life stages of fathead minnows (*Pimephales promelas* and amphipods *(Hyalella azteca)*. In: Aquatic toxicology and hazard assessment: Fifth Conference, ASTM STP 766, edited by J.G. Pearson, Robert Foster and W.E. Bishop, American Society for Testing and Materials, pp. 234–244.

Steel, R.G.D. and J.H. Torrie, 1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill, New York, 481 pp.

U.S. Food and Drug Administration, 1980. Pesticide Analytical Manual, Vol. 1, Methods which detect multiple residues. Washington, D.C.

Veith, G.D. and V.M. Comstock, 1975. Apparatus for continuously saturating water with hydrophobic chemicals. J. Fish. Res. Board Can. 32, 1849–1851.